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EFFECT OF LATERAL SHIFT OF CENTER OF GRAVITY

ON RUDDER DEFLECTION REQUIRED FOR TRIM

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EFFECT OF LATERAL SHIFT OF CENTER OF GRAVITY ON RUDDER DEFLECTION REQUIRED FOR TRIM

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SUMMARY

Tests of a single-engine scout-bomber airplane showed that the rudder deflection required for trim at low speed in the critical wave-off condition may be reduced approximately 10° by a lateral shift of the center of gravity equal to 1.8 percent of the wing span. The reduction in rudder deflection required for trim consists of the rudder deflection required to offset yawing moments from the ailerons and from the component of the weight in the direction of the longitudinal axis and the rudder deflection required to hold the sideslip angle necessary to maintain straight flight. The effect of the lateral loading must be taken into account in tests to determine the adequacy of the rudder for trim. The lateral center-of-gravity location is also important in the service operation of airplanes because, by suitable distribution of the useful load in the wings, the ability of the rudder to trim the airplane in critical power-on conditions may be markedly improved.

INTRODUCTION

Many modern single-engine airplanes have been found to have rudder control that is inadequate for maintaining straight flight at low speeds with power on. Attempts have been made to increase the amount of rudder control available by increasing the rudder chord or by offsetting the fin or the thrust line. Increasing the rudder chord may result in excessive rudder forces in maneuvers or in rudder lock. The offset fin or thrust line produces an

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asymmetrical configuration that, at high speeds, may result in excessive rudder-force changes with speed due to deformation of the surfaces under air loads.

Theoretical study indicated that a lateral shift of the center of gravity should have an appreciable effect on the rudder deflection required for trim at low speeds. Flight tests were therefore made to determine the effectiveness of this method of reducing the rudder deflection required for trim.

TEST RESULTS AND DISCUSSION

Two flights were made in a Brewster XSBA-1 airplane equipped with modified tail surfaces (fig. 1). This airplane was known to have marginal rudder control for trim in some flight conditions and was therefore chosen as representative of the type involved in the problem of providing adequate rudder control in power-on flight at low speeds. The center of gravity was shifted 4.16 inches to the right for the first flight and 4.16 inches to the left for the second flight. This shift was accomplished by asymmetric loading of fuel in the wing tanks.

The static directional-trim data presented in figure 2 were obtained from continuous records made while the speed was gradually reduced from 100 miles per hour to the stall in straight flight with the wings level. This figure contains the results of three runs made with each center-of-gravity location. The airplane was in the wave-off condition with flaps deflected, landing gear down, and maximum continuous power. The steady sideslip characteristics in the wave-off condition at approximately 60 miles per hour are shown in figure 3. Measured control-surface deflections shown in figures 2 and 3 were not corrected for cable stretch, but errors from this source are believed to be small.

The data of figure 2(a), obtained with the center of gravity 4.16 inches to the left of the thrust line, show that a rudder deflection of approximately 20° was required to trim the airplane at 50 miles per hour (5 mph above the stalling speed). Corresponding data of figure 2(b), obtained with the center of gravity 4.16 inches to the right of the thrust line, show that a rudder deflection of approximately 10° was required for trim at this speed. For the total shift of 8.32 inches (1.8 percent of the wing span) in the center of gravity, the reduction in the rudder deflection required for trim at 50 miles per hour was therefore 10°. These values were obtained from the flight runs that showed closest agreement in angle of bank. Using the average data for all three runs in each flight would give somewhat greater values for the reduction in rudder deflection. This increase in the values for the reduction in rudder deflection is thought to be caused by the small difference in the angle of bank between the two sets of runs.

The rudder forces for trim at the stall were decreased from 85 pounds to 30 pounds by shifting the center of gravity to the right. It should be noted that the direction of propeller rotation was normal, that is, clockwise when viewed from the rear.

At 50 miles per hour, the total aileron angle required for trim was 15° to the right with the left center-of-gravity location and 13° to the left with the right center-of-gravity location. The aileron angle was always well within the available range of ±40°. Since the dihedral effect was neutral as is shown in figure 3 by the fact that the aileron angle does not vary appreciably with sideslip angle, none of the change in total aileron angle required for trim was caused by the difference in sideslip angle. The difference in sideslip angle for the two center-of-gravity locations affected the rudder deflection required for trim, however, because of the inherent directional stability of the airplane.

The effect of lateral loading on the rudder deflection required for trim is believed to be caused by yawing moments that result from the aileron deflection required for trim and from the thrust required to overcome the component of weight in the direction of the longitudinal axis. When the rudder is deflected to offset these yawing moments, the side force developed on the vertical tail causes a change in sideslip angle that requires a further change in the rudder deflection for trim. Calculations based on theory indicate that these three sources of yawing moment are of about equal importance and that the estimated values are of the right order of magnitude to explain the observed effects.

The changes in rudder and aileron deflection caused by the change in lateral loading may be seen to decrease rapidly with speed - an indication that asymmetrical control deflections become very small in flight at high speed. The corresponding control forces would therefore be expected to be small at high speeds. In this respect, lateral shifting of the center of gravity is thought to be preferable to offsetting the fin or the thrust line.

The use of a lateral shift of the center of gravity to reduce the rudder deflection required for trim with power on requires rudder deflection in the opposite direction to trim the airplane at low speeds with power off. Calculations show that this rudder deflection is relatively small because the maximum lift coefficient with power off is generally much smaller than with power on. When the center of gravity is shifted laterally, a change in aileron angle is required to maintain the wings level while the normal acceleration is increased in turns or pull-ups. A total aileron angle of about 3.8° would be required in pull-ups of the XSBA-1 airplane to the stall at maximum level-flight speed with the center-of-gravity locations used in the tests. A more asymmetrical center-of-gravity location than was used in the present tests of the XSBA-1 airplane appears to have been tolerated on several airplanes in service, which have a lateral center-of-gravity shift with normal change in loading more than twice as great as that tested on the XSBA-1 airplane. Because many airplanes have provision for carrying part of their useful load in the wings, the ability of the rudder to trim these airplanes in critical power-on conditions may be improved by suitable distribution of this load. It should be noted that an airplane having counterrotating propellers, which normally needs no rudder deflection for trim, may require considerable rudder deflection for trim at low speed if the center of gravity is shifted laterally.

CONCLUDING REMARKS

The data indicated that a lateral shift of the center of gravity is an effective method of overcoming inadequate rudder control in power-on flight at low speeds. In tests to determine the adequacy of the rudder, the lateral location of the center of gravity must be taken into account.

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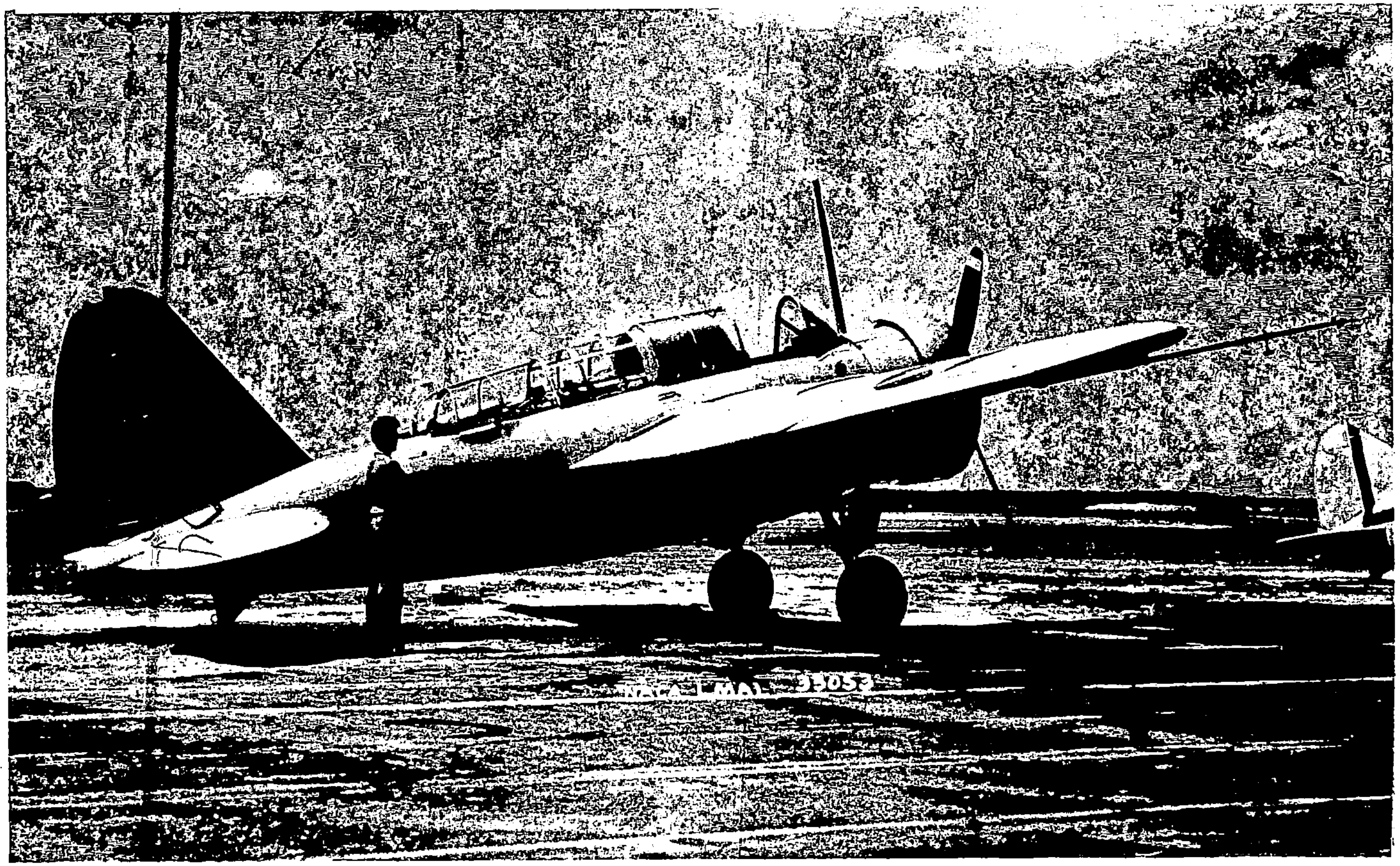
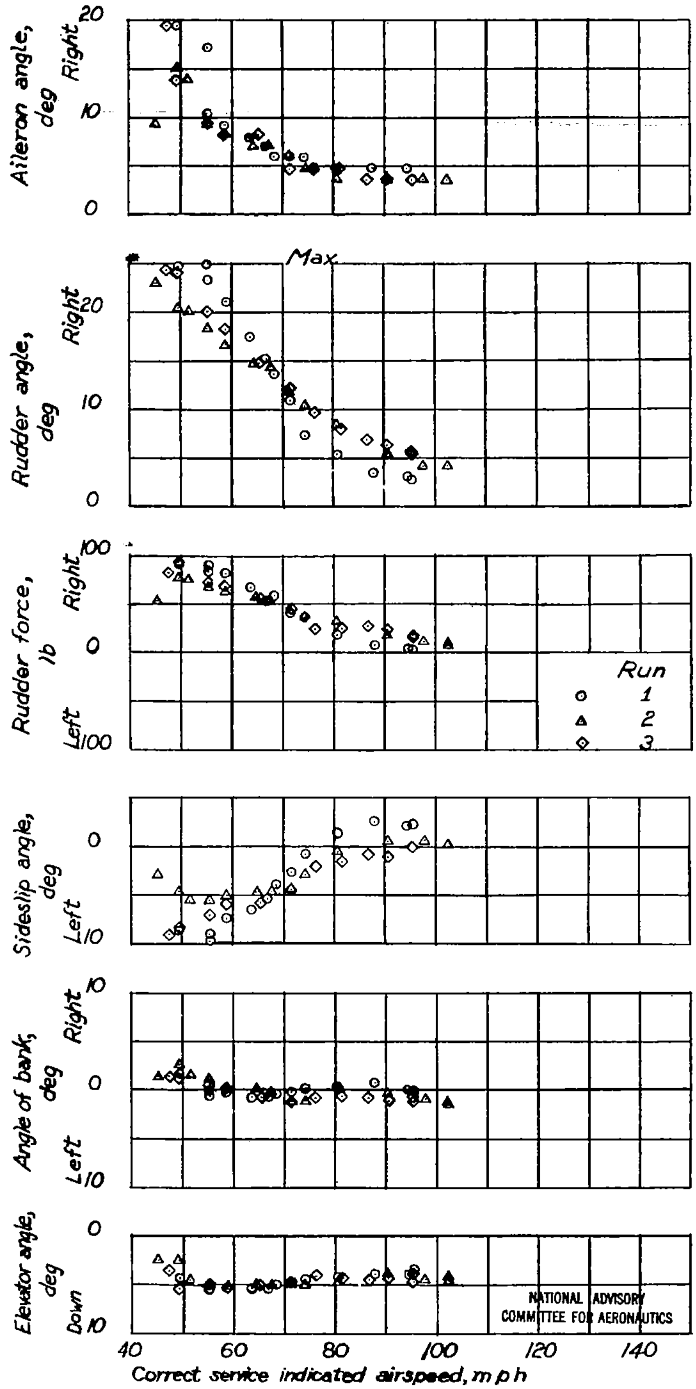
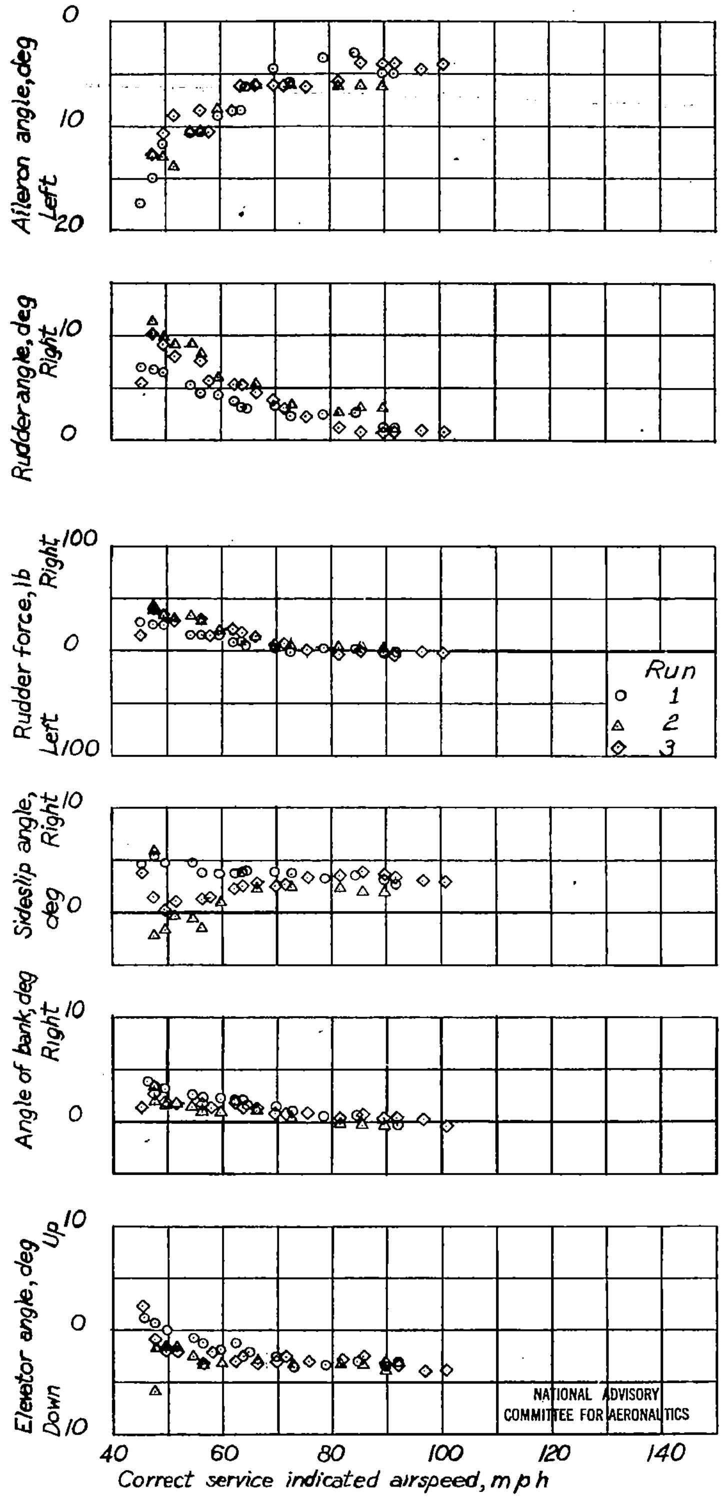


Figure 1.- Three-quarter rear view of Brewster XSBA-1 airplane used in tests.



(a) Center of gravity 4.16 inches to left of thrust line.
Figure 2. - Static directional-trim and longitudinal stability characteristics in wave-off condition (flaps deflected; landing gear down; maximum continuous power). Rudder trimming tab neutral; Brewster XSBA-1 airplane.



(b) Center of gravity 4.16 inches to right of thrust line.
Figure 2.- Concluded.

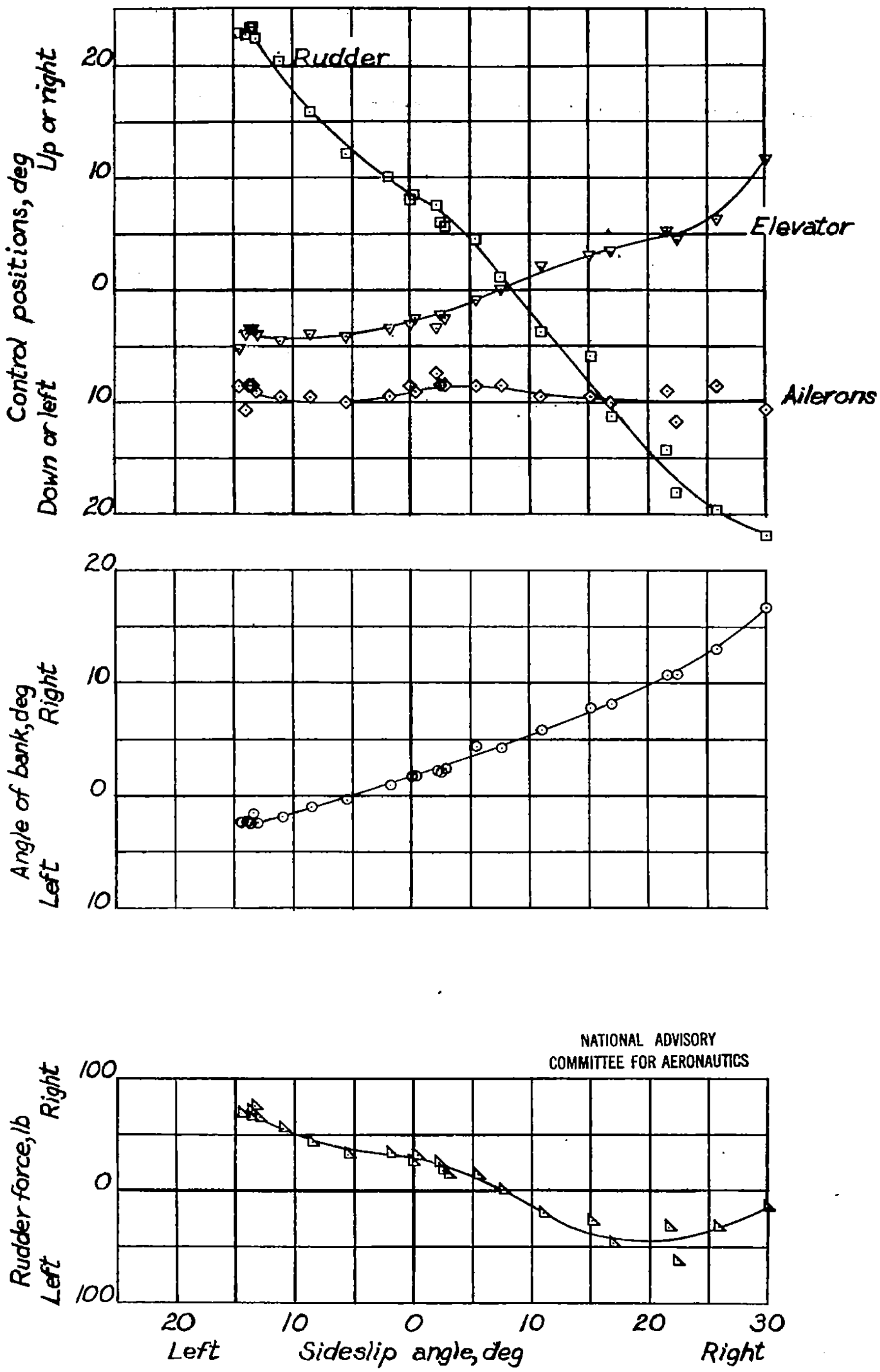


Figure 3.- Steady sideslip characteristics in wave-off condition at approximately 60 miles per hour (flaps deflected; landing gear down; maximum continuous power). Center of gravity 4.16 inches to right of thrust line; Brewster XSBA-1 airplane.